p-ISSN 2579-9150; e-ISSN 2579-9207, Volume 2, Number 1, page 1 - 13, October 2018

Indonesian Journal of
Urban and Environmental Technology
http://www.trijurnal.lemlit.trisakti.ac.id/index.php/urbanenvirotech
urbanenvirotech

MATHEMATICAL MODEL TO IDENTIFY HEAVY METAL IN IRRIGATION CHANNEL FROM CICABE FINAL DISPOSAL SITE

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ABSTRACT

Aim: This study has been done to investigate the contamination in the main open channel using mathematical modeling to describe the pollutant transport of groundwater around the Cicabe final disposal site, Mandalajati Village, Bandung (coordinate 6°53'50"S; 107°39'48"E). **Methodology and Result:** This research was conducted in the irrigation channel that crossed next to Cicabe former waste disposal site. Pollutant parameter studied was Chromium (Cr) in water and sediment. To determine the pollutant transport along flow was using the equation of 1-dimensional analytical model based on advection–dispersion phenomena. The sampling was done twice for model calibration and validation. The samples collected included sediment and water. Pollutant input generated from leachate, domestic waste, and the open channel. The Cr simulation for $k = 3 \times 10^{-4}$/sec resulted that the model concentration was quite valid to approach observed Cr in observation and calibration. Simulations also done each segment to approach Cr observation with $k_1 = 2.5 \times 10^{-4}$/sec, $k_2 = 1.1 \times 10^{-3}$/sec, and $k_3 = 0$/sec. **Conclusion, significance and impact study:** Cr concentration in the water met the quality standard according to PP 82/2011, while the Cr concentrations in sediment were above the US-EPA standard (2004). The simulation result for calibration and validation with $k = 1.4 \times 10^{-4}$ Cr/sec showed the model was sufficient approaching the observed Cr. The Cr simulation indicated that the Cr had decayed as evidenced by the quite high Cr concentration in sediment.

MANUSCRIPT HISTORY

- Received June 2018
- Revised August 2018
- Accepted September 2018
- Available online October 2018

KEYWORDS

- Advection
- Chromium
- Cicabe
- Dispersion
- Pollutant transport

1. INTRODUCTION

The waste management in Indonesia is generally centralized in one area called final disposal. Final disposal is a location accommodating solid waste from various locations in a city. The waste handling was often conducted as open dumping resulted the leachate generation that potentially contaminate ground water and surface water (Damanhuri, 2008). The problem happens when the leachate is migrated from final disposal to water body. The leachate generated from final disposal that still active and inactive is potentially to pollute environment as long it contacts with the water.

Leachate is not only generated by active final disposal, it is also generated from the inactive one as long as the waste is still degrade and contacts with water. According to Tchobanoglous (1993), the waste decomposition is occurred for 5-25 years or even more. Therefore, to minimize the final disposal impact, it is required to monitor final disposal both active and inactive one according to Law of Republic of Indonesia No. 18/2008 about The Waste Management in section 9 clause 1.

Cicabe former waste disposal site as one of inactive final disposal in Bandung City located in Mandalajati Village, Cicadas Regency was used in 1972 until 1987, and then it was opened again at 1 April–30 April 2005 and 9 January-14 April 2006. The area was 5.6 Ha with waste capacity about 105.000 m3 and it elevated in 719 – 763 m above sea water level.

Cicabe former waste disposal directly located next to the open channel flowing into Cicabe River. This research was conducted in the open channel with pollutants input derived from waste leachate, domestic wastewater, and other open channels (drainage). Therefore, to investigate the contamination in the main open channel, mathematical modeling was applied to describe the pollutant transport. Nowadays, the mathematical model for surface water quality is an efficient tool in water resources management (Benedini, 2011).

A study of groundwater around Cicabe final disposal site about several pollutant parameters had also been conducted. Cicabe waste disposal site was one of final disposal site that had been inactive since 2006 in the Mandalajati Village, Bandung. The research result on ground water by Arifandi (2011) stated that there were two sampling locations that had high index of contamination with parameters of COD, nitrate, iron and manganese. Therefore, to get an overview of the overall situation of landfill Cicabe, necessary research must be conducted regarding the surface water body located next to the final disposal.

Some previous studies on the mathematical surface water modeling ever researched by

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Harpah (2013) in the Deli River, Medan, Suprian (2012) in Kali Ciasem Bantar Gebang final disposal Bekasi, and Ani (2010) in River Murray Burn, UK. Results obtained from the studies indicated that the analytical mathematical modeling quite describing the spread of pollutants in the water body. Based on Ani, *et al* (2010), it was indicated that the concentration obtained from the analytical and numerical models had no significant difference.

2. RESEARCH METHODOLOGY

The research method consisted of primary data collection, model application, calibration and validation.

2.1 Primary Data Collection

Sampling points were split up according to the pollution source. Point 1 as starting point was before the contamination occurred. Point S1 and S2 were pollutant input. In initial characterization, samples of water and sediment were taken. The sampling points were shown in Figure 1.

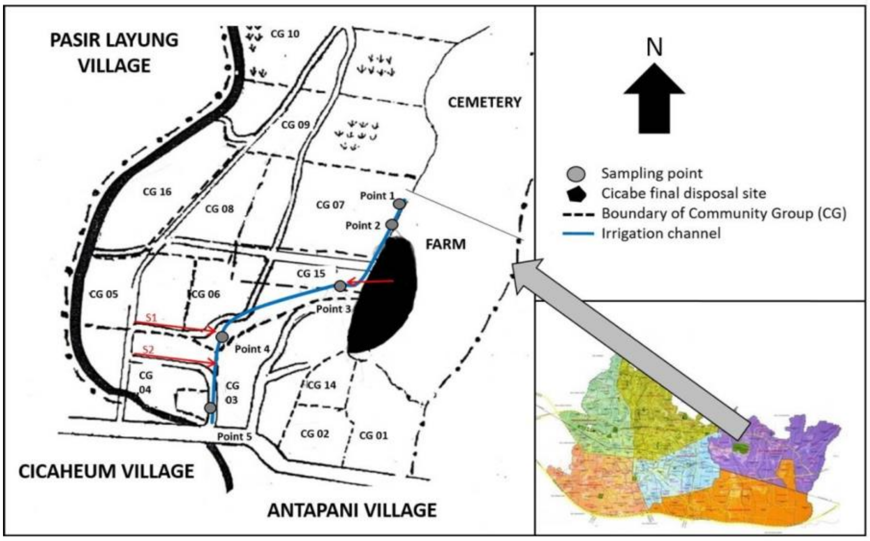

Figure 1 Sampling location

Primary data was collected sample in the field taken place in July 2013 and September 2013. From 8 points representing the location of stream. Primary data collected including hidrogeometry of stream, some physical parameter and Cr concentration in water and sediments.

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The quality of stream was considered relatively stable so that sampling conducted the grab method and examined according to Standard Method for The Examinations of Water and Wastewater (2005). Sampling segmentation was shown in Figure 2.

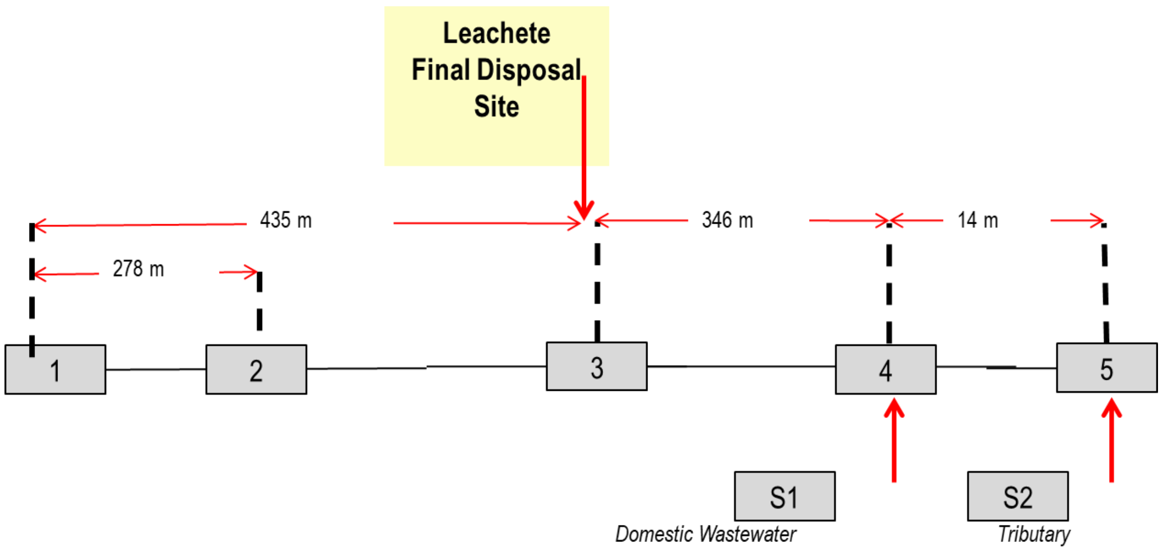

Figure 1 Sampling segmentation

2.2 Model Application

The 1-D analytic mathematic model was used to describe Cr concentration because it was assumed the dominant mixing process was the longitudinal dispersion (Jobson, 1996; Fischer et al., 1979; Chin, 2006; Wallis Manson, 2005; Ani et al., 2010). Concentration of pollutants parameters was varied along the coordinate space represented by the length, width, depth of water To determine the spread of pollutants in the stream, the 1-D model was used for Cr based Schnoor (1996), the equation regulating the advection diffusion indicated by Equation (1).

$$\frac{\partial c}{\partial t} + u_x \frac{\partial c}{\partial x} = Ex \frac{\partial^2 c}{\partial x^2} + S - R \qquad (1)$$

Where C is local concentration (mg/L); E_x is longitudinal dispersion coefficient (m^2/sec); u_x is dispersion velocity (m/sec); S is term of pollutant source (mg/L) R is kinetic process/ reaction term (mg/L). A term reaction R showed biological, physical, and chemical processes affecting the spread of pollutant. The metal has R = 0 because it includes the conservative pollutant compounds.

Assuming a semi-infinite source of contaminants, the transport equation analytic solutions to the degradation of 1-D used is Equation (2) (Fjeld, 2006). While the equation without degradation using Equation (3).

$$C(x,t) = \left[\frac{S_o}{2Q} erfc\left(\frac{x-ut}{\sqrt{4E_x t}}\right) + exp\left(\frac{ux}{E_x}\right) erfc\left(\frac{x+ut}{\sqrt{4E_x t}}\right)\right] exp\left(-k\frac{x}{u}\right) \tag{2}$$

$$C(x,t) = \left[\frac{S_o}{2Q} erfc\left(\frac{x-ut}{\sqrt{4E_x t}}\right) + exp\left(\frac{ux}{E_x}\right) erfc\left(\frac{x+ut}{\sqrt{4E_x t}}\right)\right] \tag{3}$$

Where S_o is the contaminant mass per unit time which is an initial concentration multiplied by debit, u is velocity of the stream field measurement. Estimation of longitudinal dispersion coefficient in streams using a formula developed by Fischer (1979). Fischer formula includes more parameters that allow each dispersion coefficient dependence on channels such as geometric and speed will be represented (Ani, 2010). Fischer formula is shown in Equation (4).

$$E_x = 0{,}011\ \frac{B^2u^2}{H\ U*} \tag{4}$$

with U* is *shear velocity* calculated from Equation (5).

$$U^* = \sqrt{gHS} \tag{5}$$

E_x is longitudinal dispersion coefficient (m^2/sec) and H was stream depth (m)

2.3 Model Calibration and Validation

Calibration of the model was the first stage of testing field data. The data was preliminary data that not used in building the original model. Serves as initial verification check to assess the model behavior if in accordance with the desired risk (Dahl, 2001; Suprian, 2012). Evaluation parameters were calculated using Chi-Square (Schoor, 1996) as in Equation (6).

$$X^2 = \sum_{i=1}^{n} \frac{(Y\ obs - Y\ model)^2}{Y\ model} \tag{6}$$

Where X^2 is Chi-Square distribution value; Y_{obs} is observation result; Y_{model} is the results of simulation model; n is the amount of observations.

3. RESULTS AND DISCUSSION

The analysis results mostly indicate that the concentration was within the range and not exceed the surface water quality standard class III of Government Regulation No. 82 of 2001. The discussion paper focused on the measurement of physical parameters and simulation models to the distance.

3.1 Physical and Chemical Parameters

Physical and chemical parameters measured to determine the condition of stream including pH, temperature, DHL, TDS, Dissolved Oxygen (DO), and Cr concentration in water and sediment. The pH indicates the concentration of hydrogen ions, or more precisely the hydrogen ion activity. Range pH measurements along body of water at the sampling 1 and 2 respectively ranged from 6.9 to 7.78 showed they meet the water quality standard class III of Government Regulation No. 82 of 2001, which is between 6-9, while the leachate has pH 8.14 means it was generally alkaline. The trivalent Cr is the most abundant chromium species in the sediment (Sorensen et al., 2010). In the water that is alkaline these ions to be precipitated in the bottom waters (Taftazani, 2007; Palar, 1994). The quality standard set for Cr in the sediment parameter is 76 ppm. Figure 3 shows that sample points exceed the established quality standard with the measured range: 123-167 mg/kg. The precipitation process that occurs, supported by low flow conditions ranged from 0.00127-0.2652 m^3/s. Heavy metals could accumulate in the sediment of water bodies so that their concentration will continue to increase (Begum et al., 2009). Figure 3 also shows the pH measurements of the river to the Cr concentration in the sediment at sampling 2.

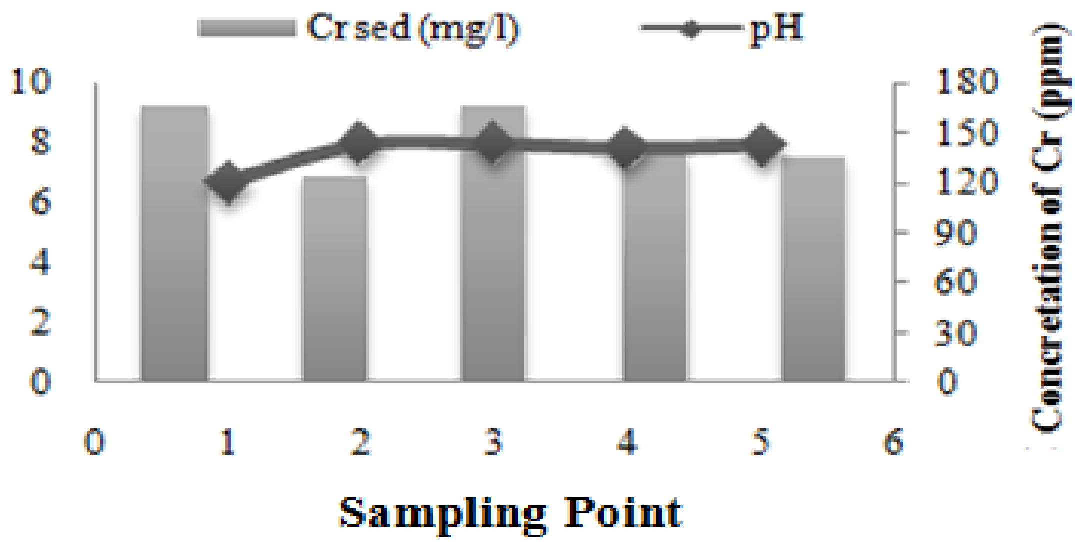

Figure 3 Parameter of pH and Cr concentration in sediment of stream

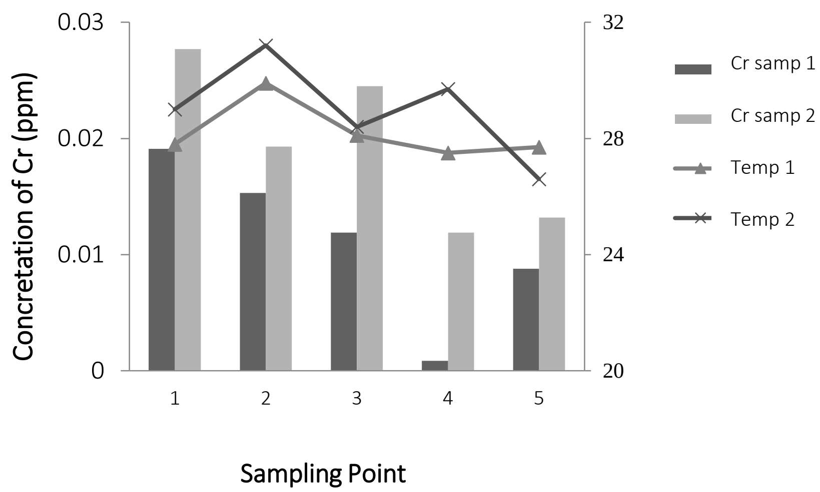

Figure 4 Parameter of Temperature and Cr concentration in water of stream

Temperature affected the saturated DO concentration in water and the solubility of the metal concentration. Figure 4 shows that the trend of the increasing temperature lead to an increasing trend of Cr concentration in water. The electrical conductivity influenced reactivity, valence number, and concentration (Naily, 2011; Effendi, 2003). The electrical conductivity was in the range from 182.2 to 777 mS/cm shown in Figure 5.

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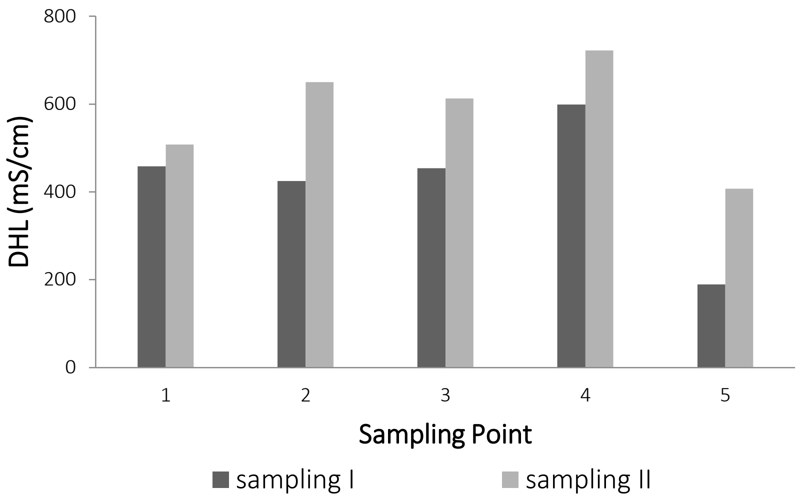

Figure 5 Electrical conductivity measurement in water body

The concentration of dissolved oxygen (DO) was useful to determine the level of pollution in the water body for self-purification process. The DO in the water depends on the physical, chemical, and biochemical activity in water. The quality standard of DO based on the Government Regulation No. 82 of 2001 for Class III water is 3 mg/L. Based on the measurements, the DO concentration sampling 1 and 2 ranged from 4.41 to 5.82 and from 5.1 to 5.7. Measurement of DO results were shown in Figure 6.

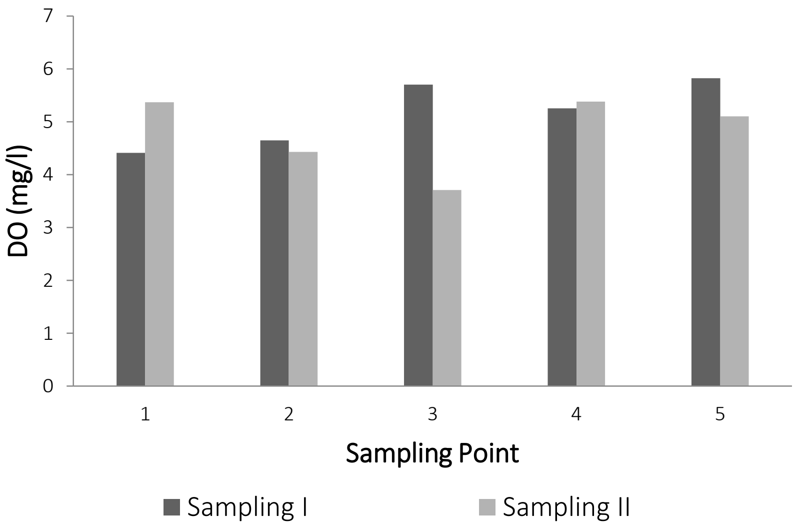

Figure 6 DO measurement in water body

3.2 Stream Hidrogeometry

The stream hidrogeometry characteristics of the stream are shown in Table 1.

Table 1 Stream hidrogeometry

Point	B (m)	H (m)	A (m^2)	U (m/s)	Q (m^3/s)	P (m)	S (m/m)	Ex (m^2/s)
1	1.30	0.175	0.256	0.168	0.0430	1.339	1.360E-04	0.1967
2	1.25	0.115	0.133	0.117	0.0160	1.256	1.438E-04	0.1603
3	2.50	0.178	0.458	0.144	0.0658	2.503	1.786E-04	0.4535
4	4.50	0.213	0.938	0.250	0.2340	4.504	4.560E-04	2.1260
5	4.50	0.325	1.950	0.126	0.2460	5.515	5.745E-05	0.8085

Where B was width, H was water depth, A was cross section area, U was water velocity, Q was discharge of the stream, P was wet area around, S was slope, dan Ex was coefficient dispersion.

3.3 Pollutant Transport Model

Transport pollutant modeling in stream in Cicabe the former final disposal using analytic solutions of advection and dispersion equation with semi-infinite pollutant sources and point source. Pollutant concentrations were assumed to be zero at t = 0. The presence of input sources with a certain concentration of pollutants issued constantly. The initial concentration was assumed to be equal to the concentration of the pollutant measurement results in point 1, the location prior to the input of pollutants from the landfill.

Initial conditions: Co = 47.47 mg/L, Q = 0.043 m^3/sec; u = 0.16817 m^2/ sec; Ex=0.19671; inputs of contaminants from leachate, waste streams from domestic and other tributary. Leachate discharge was calculated using Thorntmaite water balance method that based on the assumption that leachate produced from precipitation that managed to seep into the waste generation (percolation). Factors affecting the quantity of water percolation in the balance of this method including: precipitation, evapotranspiration, surface run-off, soil moisture storage (Damanhuri, 2008). While, the domestic wastewater discharge was calculated based on the average discharge from 1350 residents around the RW 3 in Mandalajati (Ariefandi, 2011). Input from the tributary discharge was based on field data. Simulation in terms of the change in distance up to a distance of 795 m with t = 26 years according to the age of the landfill. Each incoming inputs were assumed as a point source is added at the end of the segment and sampling locations as mass balance.

3.3.1 The Cr Transport Model

Chromium is conservative pollutant, i.e pollutants that do not experience a loss or change as a result of chemical or biochemical degradation reactions. No conservative substance concentration changes between tributaries or the input waste, the concentration changed only when there is a new source in the flow (Thomann and Mueller, 1987).

3.3.2 Sensitivity Analysis and Calibration Cr Model

Calibration was done by changing the value of kCr. As a conservative pollutant the k should be 0/sec. By using the value of kCr = 0/sec, X^2values obtained was 0.0364 with n = 4 and confidence level of 99.5%. The Cr value model k Cr = 0/sec less fit to the observed Cr concentration, therefore the simulation of various kCr: 0 - 0.0005 was held. Simulation resulted that the least X^2 value was kCr = $1.4x10^{-4}$ with confidence level of 99.5%. It is indicated that the Cr decay along the stream into sediment. That was proofed by the high concentration of Cr in the sediment which range 135-167 mg/kg. To increase the level of confidence, varied kCr values was tried as listed in Table 2.

Table 2 Calibration of Cr model

Distance	Cr_observation	kCr=0/sec		kCr=0.00014/sec		kCr=0.0003/sec	
		Cr model	X^2	Cr model	X^2	Cr model	X^2
287	0.01530	0.019100	0.0008	0.015041	0.0000	0.011447	0.0013
435	0.01190	0.019163	0.0192	0.013527	0.0002	0.009149	0.0008
781	0.00087	0.018078	0.0164	0.006161	0.0045	0.004191	0.0026
795	0.00880	0.008052	0.0001	0.006713	0.0006	0.006701	0.0007
Total			0.0364		0.00539		0.00541

3.3.3 Simulation of Cr Model

Simulation of varied kCr values in Table 2 was shown in Figure 7. From the model, it was known that the chromium degradation occurred along the stream was very few. Based on the calibration analysis, the model with kCr =1.4x10^4/sec could approach the observed data. In Figure 7 shown the results of the simulation using the kCr=0/sec, kCr=3.10^4/sec, and kCr=1.4x10^4/sec.

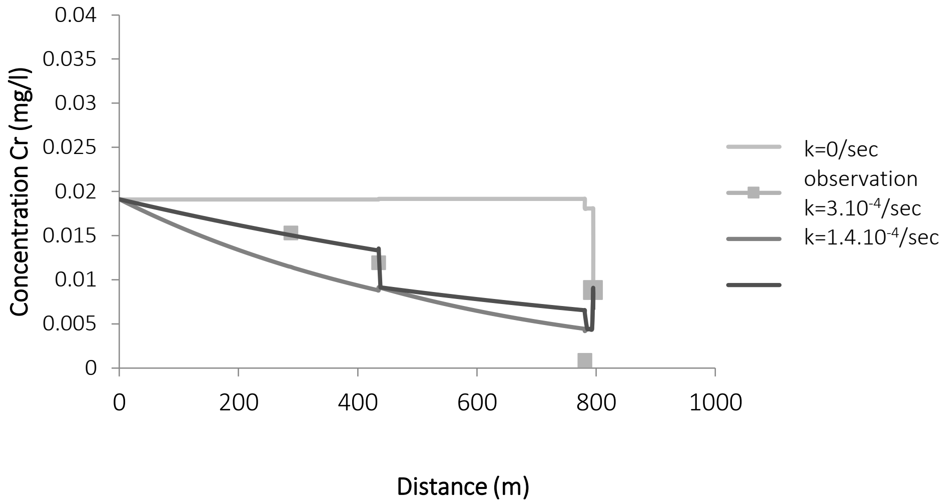

Figure 7 Simulation of 1-D model of Cr concentration with variations kCr

3.3.4 Validation of Cr Model

The Cr model validation used the second sampling data. Initial conditions: Co = 0.00191 mg L, Q = 0.00929 m^3/L, u = 0.227 m^2/sec; E_x = 1.516m^2/sec. The Cr simulation results were shown in Figure 8.

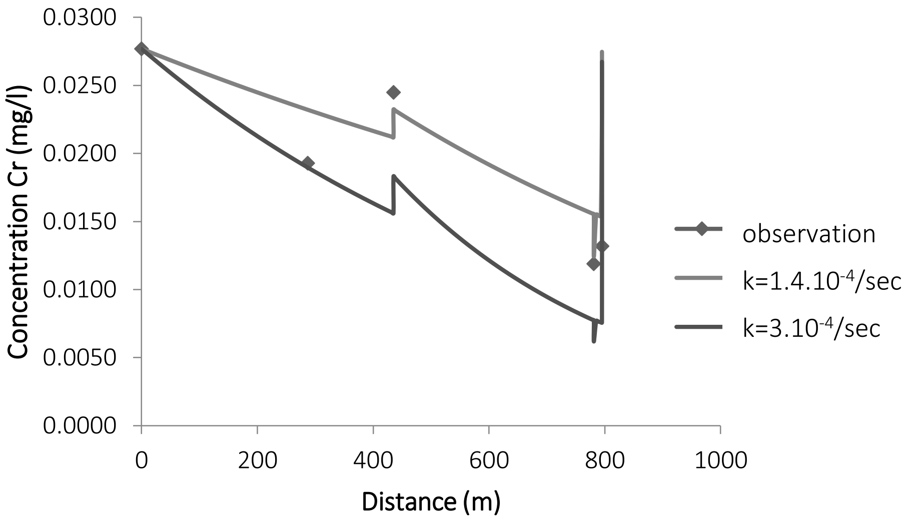

Figure 8 Validation result of Cr model

The the chi square test showed similar results to the calibration sampling 1. Simulation kCr=1.4 x10^{-4}/sec with n = 4 had the least value of X^2 with the confidence level of 99.5%.

4. CONCLUSION

From the results and the analysis obtained, it can be concluded that the results of measurements in some sampling points was indicated that the river water was not polluted by leachate from the landfill or both domestic wastewater and tributary as still meet the quality standard in Government Regulation No. 82 of 2001 for Class III based on the parameter Chromium. The COD concentration indicates not meet the quality standard in Government Regulation No. 82 of 2001 for Class III in some sampling point. The concentration of Cr in sediment indicates contamination occurred as the concentration was 123-167 ppm while by the US-EPA standards (2004) was 76 ppm. The simulation result for calibration and validation with k=1.4x10^{-4} Cr/sec shows the model was sufficient approaching the observed Cr. The Cr simulation indicated that the Cr had decayed as evidenced by the quite high Cr concentration in sediment.

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